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White Paper on Natural Gas Vehicles: Status, Barriers, and Opportunities

*A Discussion Paper for Clean Cities Coalitions and
Stakeholders to Develop Strategies for the Future*

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State of the Technology

While natural gas is often used as the energy source for residential, commercial, and industrial processes, engines designed to run on gasoline or diesel can also be modified to operate on natural gas — a clean burning fuel. Natural gas vehicles (NGVs) can be dedicated to natural gas as a fuel source, or they can be bi-fuel, running on either natural gas or gasoline, or natural gas or diesel, although most natural gas engines are spark ignited. Natural gas engine technologies can differ in the following ways: the method used to ignite the fuel in the cylinders, the air-fuel ratio, the compression ratio, and the resulting performance and emissions capabilities. Natural gas has a high octane rating, which in spark ignition engines (usual for CNG) allows an increase in power. However, natural gas occupies a larger volume in the cylinder than liquid fuels, reducing the number of oxygen molecules (share of air in the cylinder), which reduces power. The net effect on natural gas power vs. gasoline is relatively neutral. However, since it is a gaseous fuel at atmospheric pressure and occupies a considerably larger storage volume per unit of energy than refined petroleum liquids, it is stored on-board the vehicle in either a compressed gaseous or liquefied state. The storage requirements are still much greater than for refined petroleum products. This increases vehicle weight, which tends to reduce fuel economy. To become compressed natural gas (CNG), it is pressurized in a tank at up to 3,600 pounds per square inch. Typically, in sedans, the tank is mounted in the trunk or replaces the existing fuel tank; on trucks, the tank is mounted on the frame; and on buses, it is mounted on top of the roof. Although tanks can be made completely from metal, they are typically composed of metal liners reinforced by a wrap of composite fiber material with pressure-relief devices designed to withstand impact. Tanks do increase the vehicle weight, and with the lower energy density of natural gas, vehicle ranges are generally reduced. To become liquefied natural gas (LNG), natural gas is cooled to -260 °F and filtered to remove impurities. LNG is stored in double-wall, vacuum-insulated pressure tanks and is primarily used on heavy-duty trucks, providing increased range over CNG.

NGVs and their respective fueling systems must meet stringent industry and government standards for compression, storage, and fueling. They are designed to perform safely during both normal operations and crash situations. Nozzles and vehicle receptacles are designed to keep fuel from escaping during refueling by locking together to form a sealed system. In the case of a vehicle fire or impact, a pressure-relief device in the cylinder allows for controlled venting of the gas so pressure is not built up in the tank. Cylinders are to be inspected by a qualified cylinder inspector every 3 years or 36,000 miles, whichever comes first, for deterioration or damage. After several decades of NGV operations, there has been only one fatality in the United States; it was caused by a breach in an NGV's fuel system, which resulted from noncompliance with existing safety standards (NGVAmerica, 2009a.)

Current Market Status

Vehicles/Engines

According to the *Annual Energy Review 2008 and other data*, published by the U.S. Department of Energy (DOE)/Energy Information Administration (EIA), less than 0.03 percent of natural gas is currently used in the transportation sector (compared to volumes delivered to other customers) (EIA, 2009 [June]). The number of NGVs in use was estimated at 117,000 NGVs in 2007 (EIA, 2009[April]). The Clean Vehicle Education Foundation reports that the inventory of NGVs in 2008 is more likely to be about 105,000 vehicles, after having peaked in 2003 (Yborra, 2008). The International Association of Natural Gas Vehicles estimates that more than 9.5 million NGVs currently ply the roads globally, with an annual average 30 percent growth rate since 2000 (IANGV, 2009).

In general, the NGV strategy in the United States has been to pursue high-fuel-use, urban fleets capable of central refueling. This market includes fleets of buses, trash haulers, taxis, and shuttle, delivery, port, and airport vehicles. According to the American Public Transit Association *2009 Public Transportation Fact Book*, nearly 19 percent of the nation's full-sized transit bus fleet, or about 12,000 vehicles, operate on natural gas (APTA, 2009). Furthermore, 2.7 percent of U.S. paratransit fleets operate on natural gas. Paratransit is defined as an alternative mode of flexible passenger transportation that does not follow fixed routes or schedules (Wikipedia.org). In addition to these statistics, the Clean Vehicle Education Foundation estimates there are approximately 3,000 natural gas refuse haulers, 2,800 natural gas school buses, and 16,000–18,000 medium-duty NGVs, such as airport shuttles and delivery vans. The remaining inventory includes about 65,000–75,000 light-duty NGVs (Yborra, 2008).

All but one domestic light duty vehicle manufacturer (except for American Honda) completely exited the CNG vehicle market in 2006. However, technological innovation for commercial vehicle use has led to current availability of clean natural gas engine options in that market segment. The manufacturers of these engines succeeded in meeting strict 2010 emissions standards for vehicles intended primarily for commercial use. These vehicles are 8500lb and above Gross Vehicle Weight (GVW). They are currently tested on engine dynamometers, with a totally different set of regulations than for vehicles below 8500 GVW, where vehicle dynamometers are used. There are a number of ways of defining the attributes of commercial vehicles (Bertram et al, 2009). Light duty could refer to “class 2b” vehicles — mostly 4 tire, two axle, pickup trucks, which use both gasoline and diesel engines. Medium refers predominantly to two or more axle trucks with six or more tires on a single body (a single unit). For purposes of this paper it is useful to think of “heavy” commercial trucks as two types – single unit and combination trucks. The former are conceptually similar to the two axle, four and six tire light and medium trucks, and generally serve urban areas. Combination trucks (the dominant type is often called an “18 wheeler”) have a tractor and trailer and specialize in inter-city movement of goods. Combination trucks effectively use only diesel engines. Nevertheless, according to Bertram et al, in 2002, about 38% of fuel used in commercial trucking was gasoline. Considering the fact that combination trucks use only diesel fuel, the Bertram et al numbers

imply that more than half of the 2002 light and medium duty commercial truck fuel use was gasoline, though diesel's share was steadily increasing.

For medium- and heavy-duty NGVs, the primary engine manufacturers are Cummins Westport Inc. (CWI) (<http://www.cumminswestport.com>), Westport Innovations (<http://www.westport.com>), and Emission Solutions, Inc. (ESI) (<http://www.emissionsolutionsinc.com>). John Deere recently left the CNG engine market but still offers repair and maintenance services. Daimler Trucks North America recently teamed up with CWI to offer the Freightliner Business Class® M2 112 medium duty truck equipped with the Cummins ISL G natural gas engine. The truck will be offered in six CNG/LNG tractor and truck configurations, and the entire line will be available by the end of 2010. This would cover 90 percent of all North American truck applications, according to Roe East, CWI President (Consensus, 2009).

According to the *Guide to Available Natural Gas Vehicles and Engines* (Yborra, 2009), the manufacturers listed in Table 1 currently produce natural gas engines which are conversions of diesel engines.

Table 1: Manufacturers of Natural Gas Engines

| Manufacturer | Engine Type | Application | Certification |
|--------------------------|--|--|--|
| Cummins Westport Inc. | 5.9L B Gas Plus (Spark-Ignited) | Medium-duty (e.g., school buses/shuttles); production will end 12/31/09. | EPA 2007 Compliant |
| Cummins Westport Inc. | 8.9L ISL G (Spark-Ignited) | Heavy-duty (refuse, transit/D4 school buses, street sweepers, yard hostlers) | EPA 2010 compliant (0.2 NO _x and 0.01 PM g/bhp-hr) |
| Emission Solutions, Inc. | 7.6L NG Phoenix (Spark-ignited) remanufactures International Navistar DT 466 diesel platform to NG | Medium-duty school buses/heavy-duty cutaway shuttles and work trucks | CARB/EPA 2010 compliant (0.2 NO _x and 0.01 PM g/bhp-hr) |
| Westport Innovations | 15L GX (compression ignited) dual fuel high pressure direct injection (95% natural gas, 5% diesel) | Heavy-duty (work trucks and line-haul applications) | EPA 2007 compliant |

Two of the four are listed as 2010 compliant. However, the smaller of the engines — suitable for light duty trucks where gasoline's share is highest — is scheduled to cease production.

In addition, several companies, including BAF Technologies and Baytech Corporation, offer dedicated CNG and bi-fuel retrofits of Ford (BAF) and GM (Baytech) gasoline engines primarily for cutaway chassis for shuttles, box trucks, and Workhorse walk-in van chassis. Both companies have received California Air Resources Board (CARB)/EPA certification for certain MY 2009 vehicle chassis. In a recent development, Ford has begun to offer its fleet customers a 2010 model year gaseous fuel option for its full line of E-Series vans with a 5.4 liter engine and will later make this option available in its 6.8 liter engine (Ford.Media.Com., Sept. 15, 2009, NGVAmerica, 2009b). In contrast, Navistar is planning to discontinue its V6 MaxxForce 5 V6 diesel engine in the U.S., due to difficulty in meeting 2010 standards (Light and Medium Truck, Sept. 2009).

In light duty vehicles below 8500 GVW, natural gas vehicle availability peaked in 2002 and dropped sharply thereafter, with only one OEM option available since 2005 (AFDC 2009a). From 1996 to 2009, American Honda has offered the Civic GX in quantities of about a thousand per year, in a limited number of states, to fleet operators and is now also offering it to private customers, also in targeted markets. This dedicated natural gas sedan has been rated by the American Council for an Energy Efficient Economy as the cleanest internal-combustion-engine vehicle (ICEV) available in the U.S., for several years. Honda began its 2010 model year production run for the GX in Indiana on May 13 (Hondanews.com, 5/13/2009). It initiated retail sales of the GX in the state of California in 2006 (42 dealers sell retail now) and in the state of New York in 2007 (nine retail dealers now), and just recently added sales in eight dealerships in Utah (Hondanews.com, 7/30/2009). The American automakers formerly offered bi-fuel and dedicated NGVs, with the number of options peaking in 2002 at 18, falling to just five models in 2005. The Civic GX has been the only CNG light duty vehicle offered since 2007. The American manufactured vehicles, however, did not always have lower criteria pollutant emissions operating on natural gas than did comparable models with the same engine size. When running on gasoline, the Cavalier bi-fuel CNG/gasoline vehicle had slightly worse fuel economy than the comparable dedicated gasoline vehicle, probably as a result of added storage system weight. Based on today's EPA ratings of past CNG vehicles, for criteria pollutants, on average they were comparably clean to gasoline vehicles. "Energy equivalent" fuel economy was consistently less, but due to favorable properties of natural gas, net estimates of tons of GHGs emitted are generally less. According to the DOE/EPA fueleconomy.gov website, the 2009 Civic GX emits an estimated 5.4 tons of CO₂ per year, compared to 6.3 tons for the standard Civic, an improvement of 14%. Criteria air pollutants rates a score of 9.5 (of 10) in low emissions states, and 9 elsewhere, while the standard Civic has ratings of 6 and 7, respectively. The *degree* of superior performance of the GX against gasoline does not appear to be inherent to CNG. American manufacturers did not reproduce this degree of superiority in past models.

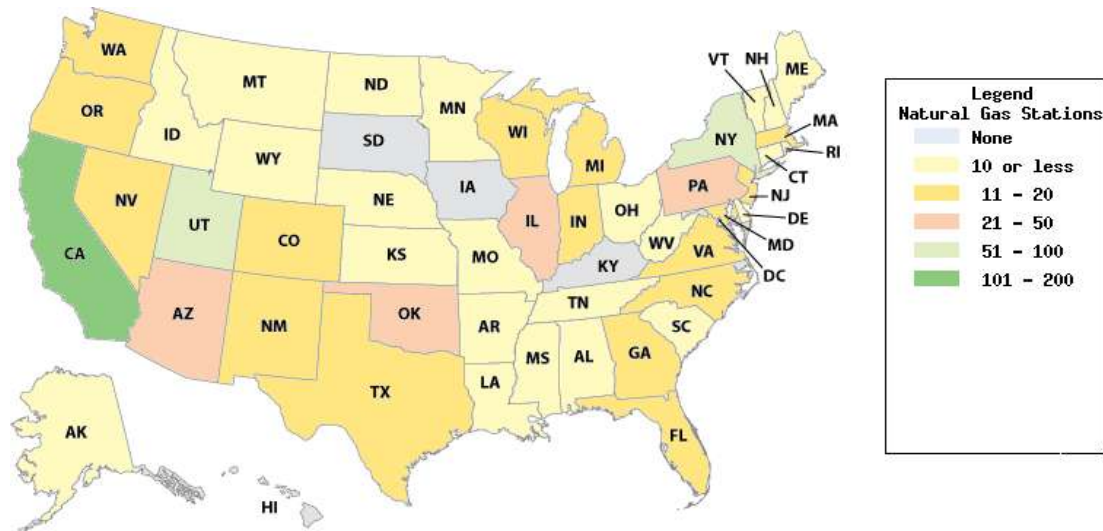
At the 2008 Los Angeles Auto Show, Toyota showed a prototype CNG hybrid sedan. At the 2009 Washington Auto Show, Mercedes Benz displayed a CNG compact car, with the intent of someday introducing it to the U.S. market. Fiat's merger with Chrysler could also result in NGV models in the future, because this automaker is the largest manufacturer of models of this fuel type, including the tetrafuel option, which allows for the vehicle to be fueled on any level of ethanol, natural gas, or gasoline (Siuru, 2009). In addition, a few companies currently offer equipment certified by the U.S. EPA to allow for conversion to light-duty NGVs.

Infrastructure

NGVs are fueled either with CNG, which is delivered through the pipeline system, or LNG, which is normally delivered by truck to the fueling station. The fuel can be made available at public stations, private fleet facilities, or even homes. Public natural gas stations have pumps that are similar in design to typical gasoline or diesel pumps and that have comparable filling times. Private facilities are used by dedicated fleet(s) and are either fast-fill or time-fill (i.e., tanks are filled over an extended period of time). For LNG, after the fuel is delivered to the fleet facility, it is stored in specially designed cryogenic storage tanks and pumped into vehicles in much the

same way as other liquid fuels. According to the DOE Alternative Fuels and Advanced Vehicles Data Center (AFDC), there are 773 public and private CNG stations and 35 LNG stations in the United States (see figure 1) (AFDC, 2009a).

Figure 1: Natural Gas Stations by State



Source: AFDC, 2009b.

In support of the Honda GX, a home fueling appliance, known as *Phill*, manufactured by FuelMaker Corporation, was available in limited markets until recently. The retail price of the home refueling appliance, *Phill*, has been approximately \$3,000 to \$4,000, with an installation fee of \$1,000 to \$2,000 (German, 2008). Federal income tax credits are available to offset the cost of each of these options. In addition, many states and air quality districts offer incentives, and some utilities offer preferential gas rates to *Phill* customers.

Approximately 400 units have been sold. FuelMaker declared bankruptcy in early April 2009, and Fuel Systems Solutions, Inc. made an offer to buy and continue the business activities of the former company (NGVA, 2009c). The *Phill* is connected to home gas and electricity supplies and mounted either in garages or on outside walls. Depending on the amount of fuel already in a tank, 4–12 hours are required to complete the fill. A full tank gives the typical consumer a fuel supply that is much more than is needed for the average daily vehicle miles of travel, which is 32.7 miles (Davis, Diegel, and Boundy, 2008).

The cost of the far more common method of refueling natural gas vehicles worldwide — a refueling station with fuel delivery equipment comparable to that found at gasoline stations — depends on the type of fueling equipment used: fast-fill or time-fill. When a high-pressure storage system is combined with a large compressor in a fast-fill station (the most comparable configuration to gasoline refueling), the cost is higher than in a time-fill system, which has no storage system and a smaller, less expensive compressor. According to Doug Horne of the Clean Vehicle Education Foundation, the range in the cost is tied to the utilization of the station and

usually the larger the station and the higher the utilization the lower the cost per GGE delivered. To the end user the cost per GGE is most important since that is what they see as a cost for operating their vehicles. Total infrastructure costs include the following:

Electric compression costs (estimated @ 1KWh/GGE): \$.09 -.15/GGE

Maintenance/Repair/Service fund: \$.15-35/GGE

Capital amortization of equipment: \$.35-.65/GGE

Summing the low values results in an estimated cost of \$0.59/GGE at the low end, and \$1.15 \$/GGE at the high end. These costs do not include the amortized incremental CNG vehicle costs.

Natural Gas Fuel and Vehicle Pricing

On the basis of historical data from 2004 to 2007, the Energy Management Institute reports that natural gas was 48.6 percent less costly than petroleum-based fuels (*Natural Gas Fuels, 2007*). More recently, the percentage difference has declined somewhat. See Table 2 below for a recent history of average monthly prices for the three fuels as reported in the *Clean Cities Alternative Fuel Price Reports* (AFDC, 2009c).

Table 2: Monthly Average Price of Gasoline, Diesel, and Natural Gas (per GGE)

| | Gasoline | Diesel | Natural Gas |
|---------------|-----------------|---------------|--------------------|
| July 2009 | \$2.44 | \$2.27 | \$1.73 |
| April 2009 | \$2.02 | \$2.26 | \$1.64 |
| January 2009 | \$1.86 | \$2.19 | \$1.63 |
| October 2008 | \$3.04 | \$3.27 | \$2.01 |
| July 2008 | \$3.91 | \$4.22 | \$2.34 |
| April 2008 | \$3.43 | \$3.71 | \$2.04 |
| January 2008 | \$2.99 | \$3.05 | \$1.93 |
| July 2007 | \$3.04 | \$2.65 | \$2.10 |
| March 2007 | \$2.30 | \$2.35 | \$1.94 |
| June 2006 | \$2.84 | \$2.67 | \$1.90 |
| February 2006 | \$2.23 | \$2.48 | \$1.99 |

Source: AFDC, 2009c, *Clean Cities Alternative Fuel Price Report*

Larger natural gas fleets have the ability to negotiate and secure long-term prices from commodity brokers, potentially escaping volatile price spikes in the cost of natural gas acquisition. Compared to prices of natural gas for home heating (both wholesale and retail), prices of natural gas as a motor fuel for commercial fleets have been more stable because of the greater ability of fleets to lock in the unit gas price at a fixed rate for a relatively long period.

For light-duty CNG sedans, the cost of the Honda Civic GX is about \$6,935 higher than that of its gasoline counterpart, but tax credits at the federal and often the state and local levels are available to help offset this cost (Cook, 2009).

For medium- and heavy-duty NGVs, in previous years, the incremental cost ranged from \$20,000 to \$50,000 more than that of comparable diesel vehicles. However, the prices of

medium- and heavy-duty NGVs are narrowing with those of equivalent diesel vehicles, as manufacturers adopt technology to meet tough 2010 emission standards. Volvo AB has recently announced that it “would level a ‘non-negotiable surcharge’ of more than \$9000 to cover the costs of its U.S. 2010 emissions technology.” (Light and Medium Truck, Sept. 2009). Navistar said it would add \$6000 to the cost of MaxxForce 7, 9, 10 and DT medium duty engines, and \$8000 to the 11, 13, and 15 heavy duty engines. (Light and Medium Truck, Sept. 2009). The Volvo AB technology uses urea, called “diesel emissions fluid” (DEF), which will add to the cost of operations as well as the first cost of the vehicle. The earlier anticipatory TIAX LLC conclusion that natural gas would become competitive with clean diesel was based on a life-cycle cost analysis of owning, operating, and maintaining diesel and natural gas heavy-duty engines in compliance with 2010 EPA emission standards. It is an important prediction, because in 2004 heavy-duty diesel engines had a significant cost advantage over natural gas engines. After 2010, TIAX estimated that natural gas refuse haulers, transit buses, and short-haul trucks will have a cost advantage as long as oil prices are more than \$31 a barrel (TIAX, 2005).

Natural Gas Supply

Fossil natural gas. Most of the natural gas consumed in the United States is fossil fuel produced domestically by drilling. About 16 percent is imported, either in gaseous form, via Canadian pipelines, or as LNG, primarily from Trinidad and Tobago (EIA *Natural Gas Annual* 2009a[Feb]). Significant additional supplies continue to come from the Lower 48 States, mainly from unconventional resources, such as shale. Shale formations in the Lower 48 States are widely distributed and hold vast amounts of natural gas. One shale field in Texas produced 5 percent of the Lower 48 States’ natural gas supply in 2007 (EIA, *U.S. Crude Oil, Natural Gas, and Natural Gas Liquids Reserves Report* 2009b[Feb]). Advanced drilling technologies (e.g., horizontal drilling and hydrofracturing) are helping to spur increases in supply, because they allow for the economic production of natural gas from complex geologic formations. From 1998 to 2007, the number of U.S. proven dry natural gas reserves rose every year. Neither the 45 percent rate of increase since 1998 nor the increase in quantity of 74 trillion cubic feet (EIA, *U.S. Crude Oil, Natural Gas, and Natural Gas Liquids Reserves Report* 2009b[Feb]) has been exceeded during the past 54 years of 9-year periods (EIA, 2009c). In this same time interval of 1998 to 2007, the U.S. proven oil reserves increased by only 1.3 percent. Over the same 9-year period, natural gas consumption increased by less than 4 percent (EIA, *Natural Gas Navigator Website. Natural Gas Reserves Summary as of Dec. 3, 2009c[Feb]*). The Potential Gas Committee (PGC), a nonprofit organization, which receives guidance from the Colorado School of Mines, recently reported its latest results of its biennial assessment of the U.S. natural gas resources and concluded that the United States possesses a total resource base of 1,836 trillion cubic feet (Tcf), the highest assessment in its 44-year history. The PGC states that most of the increases result from the reevaluation of shale gas in the Appalachian basin, Mid-Continent, Gulf Coast, and Rocky Mountains (PGC, 2009). Tapping unconventional resources will continue to play a significant role in natural gas supply; accordingly, the issue of natural gas availability in the United States is not a near-term concern. Rather, the concern is how to put natural gas resources to their best use in order to improve energy security and the environment.

Renewable natural gas. Renewable natural gas, or biomethane is the result of anaerobic digestion of organic matter, such as municipal solid waste or animal waste. Once the biogas is

filtered to a higher quality and either compressed or liquefied, it can be used to fuel standard NGVs, such as refuse trucks, buses, or municipal vehicles. In the United States, conversion of landfill gas to natural gas fuel is slightly past the demonstration stage; the process has been demonstrated in California and New Jersey and is now being implemented on a commercial scale in Columbus, Ohio, and Orange County, California. However, most of the biogas vehicles in operation today are in Europe. Biogas is an important component in meeting the European Parliament's target of 10 percent biofuel use in transport by 2020 (European Commission, 2007). To date in the U.S. only small quantities of methane have been derived from surface biomass.

Transition to Hydrogen

Since natural gas is rich in hydrogen atoms and low in carbon, it is a very good feedstock for producing hydrogen gas. Hydrogen can be produced from natural gas by using high-temperature steam (i.e., steam methane reforming), which is the most common way, or by partial oxidation, which produces hydrogen by burning methane in air. Both methods result in "synthesis gas," which is reacted with water to produce more hydrogen. In addition, natural gas is sometimes touted by industry as a pathway to the hydrogen future, because some aspects of hydrogen and natural gas distribution are similar, such as fuel storage, fueling, station siting, and training of technicians and drivers. It is generally believed that the knowledge gained from using natural gas for transportation will make the transition to a hydrogen economy easier.

As another stepping-stone to a hydrogen future, natural gas can also be blended with hydrogen to make a transportation fuel: either 20 percent by volume hydrogen (Hythane™) or 30 percent by volume hydrogen (HCNG). Thus far, this technology has been limited to demonstration programs involving either transit or private fleets. The key advantage of hydrogen-enriched natural gas is its potential to satisfy tougher emission standards without requiring the installation of expensive exhaust after-treatment devices. Hythane has been shown to maintain fuel efficiency and reduce emissions of nitrogen oxides (NO_x) in a conventional natural gas engine without imposing major conversion costs. The HCNG blend has demonstrated that it can meet strict NO_x standards, preserve fuel efficiency, and avoid expensive three-way catalysts; however, it requires expensive engine modifications.

Therefore, if the use of hydrogen-enriched natural gas becomes more common, the 20 percent blend could be used in existing natural gas engines and the 30 percent blend could be used in new engines manufactured to operate specifically on that fuel. Few modifications are needed to add a hydrogen-enriched natural gas option to an existing CNG station. One market barrier is that the two different fuel formulations could require fleet operators to commit to the long-term use of refueling equipment, suppliers, and vehicles. The major barrier to the use of hydrogen-enriched natural gas, however, remains the high unit costs of the initial infrastructure due to diseconomies of small initial scale. Further, no standard design yet exists, so no two infrastructure projects are alike (Mintz et al., 2007).

Available Federal Incentives

Incentives for natural gas fuel, vehicles, and infrastructure exist due to federal laws (see table 3).

Table 3: Federal Laws with Incentives for Natural Gas Fuel, Vehicles, and Infrastructure

| Incentive Type | Federal Law | Provision |
|-----------------------|--|--|
| <u>Fuel</u> | Safe, Accountable, Flexible, Efficient Transportation Equity Act: A Legacy for Users, P.L. 109-59 (8/10/05) (SAFETEA LU) | An excise tax credit is available for an alternative fuel that is sold for use or used as a fuel to operate a motor vehicle. The credit is \$0.50 per gge of CNG and \$0.50 per liquid gallon of liquefied petroleum gas (LPG), LNG, and liquefied hydrogen. The entity eligible for the credit is the one liable for reporting and paying the federal excise tax on the fuel. The tax credit is also available to nonprofit tax-exempt entities that fuel on site. The excise tax credit, paid from the General Revenue Fund, is partially offset by an increase in the motor fuel excise tax rate for CNG/LNG, which is now on parity with that for other motor fuels. |
| | Emergency Economic Stabilization Act/Energy Improvement and Extension Act of 2008 P.L. 110-343 (10/3/08) | Section 204 amends the expiration date for existing alternative fuel excise tax credit from September 30, 2009, through December 31, 2009. |
| Vehicle | Energy Policy Act of 2005, P.L. 109-58 (8/8/05) | <p>A “qualified alternative fuel motor vehicle” tax credit is available for the purchase of a new, dedicated, or repowered alternative fuel vehicle. It is for 50% of the incremental cost of the vehicle, plus an additional 30% if the vehicle meets certain tighter emission standards. These credits range from \$2,500 to \$32,000, depending on the size of the vehicle. The credit is effective on purchases made after December 31, 2005, and expires on December 31, 2010. The vehicle must be acquired for use or lease by the taxpayer claiming the credit.</p> <p>a. The credit is only available to the original purchaser of a qualifying vehicle. If a qualifying vehicle is leased to a consumer, the leasing company may claim the credit.</p> <p>b. For qualifying vehicles used by a tax-exempt entity, the person who sold the qualifying vehicle to the person or entity is eligible to claim the credit, but only if the seller clearly discloses in a document to the tax-exempt entity the amount of credit. The seller may pass along any savings of the tax credit but is not required to do so. The IRS does not set limits on the amount of credits claimed by any one entity.</p> |
| Infrastructure | Energy Policy Act of 2005, P.L. 109-58 (8/8/05) | An income tax credit is available. It is equal to 30% of the cost of natural gas refueling equipment, up to \$30,000 in the case of large stations and \$1,000 for home refueling appliances. The credit is effective on purchases placed in service after December 31, 2005, and expires on December 31, 2010 (due to passage of the Emergency Economic Stabilization Act, P.L. 110-343). |
| | American Recovery & Reinvestment Act of 2009, P.L. 111-5 (2/17/09) | This act increases the value of the credit for the purchase of equipment used to store and dispense qualified alternative fuels, placed in service during 2009 and 2010. The credit for these years is \$50,000 or 50% of the cost, whichever is smaller, for business property and \$2,000 or 50% of the cost, whichever is smaller, for home refueling. |

Sources: AFDC 2009d; NGVAmerica, 2009d.

State tax credits for fuel, vehicles, infrastructure, and business development exist in 25 states and further aid in the development of the market.

Examples of State Incentives for Natural Gas Vehicles

While many states offer incentive programs for natural gas vehicles, Colorado and Utah are highlighted for the purpose of this report.

Colorado. Colorado provides alternative fuel infrastructure and vehicle tax credits. An income tax credit is offered for the cost of construction, reconstruction, or acquisition of an alternative fuel station. For the tax period 2009–2011, this credit is 20 percent. If the station is publicly accessible, the percentage is multiplied by 1.25. If at least 70 percent of the alternative fuel is produced from renewable sources for a period of 10 years, an additional credit of 1.25 is multiplied. Additionally, the vehicle tax credit is available on the purchase of or conversion to an alternative fuel vehicle. The tax credits range from 25 percent to 85 percent of the incremental cost or conversion costs of vehicles classified as low emission vehicle or better. This credit has the potential to double if the purchase or conversion permanently replaces a motor vehicle that is 10 years old or older, up to 100 percent of the incremental or conversion cost. The law allows the taxpayer to carry forward for 5 years any excess should the credit exceed the person's tax liability for the year in which the vehicle was purchased or converted. Generous rebates are available to tax-exempt organizations wishing to purchase or convert to an alternative fuel vehicle (AFDC, 2009d).

Utah. Among other states, Utah offers a clean fuel vehicle tax credit providing for 35 percent of the incremental cost (up to \$2,500) of a clean fuel vehicle manufactured by an original equipment manufacturer or an income tax credit for 50 percent of the cost (up to \$2,500) of a conversion during the time period of January 1, 2009 to December 13, 2013. The state has also offered similar tax credits in previous periods. Salt Lake City has an alternative fuel vehicle parking program, in which those vehicles do not have to pay metered public parking. The Salt Lake City Department of Airports also provides a credit against ground transportation fees to commercial ground transportation providers exclusively using clean fuels. The Public Service Commission has the authority to approve requests by gas utilities for a special NGV rate that is less than full cost and can allocate these additional costs to remaining rate payers. As in several other states, clean fuel vehicles in Utah are allowed to travel in high occupancy vehicle (HOV) lanes regardless of the number of passengers. Furthermore, in a recent House Concurrent Resolution, the state encouraged the U.S. EPA to adopt practices to facilitate vehicle conversions for small-volume manufacturers (AFDC, 2009d).

Emission Benefits of Natural Gas Vehicles

Because of regional differences in fuel composition and engine configurations, potential “in-use” emission reductions from the deployment of NGVs (certification test results are based on standard fuels, which are generally not the same as used in the field) can vary. Compared to conventional gasoline light-duty vehicles (LDVs), according to the fueleconomy.gov website,

natural gas LDVs generally reduce smog producing pollutants by 60-90%. The EPA has for many years rated the Honda Civic GX as the cleanest ICEV in the world. The GX is the only non-hybrid to score 9 or higher (out of 10) on both EPA's Air Pollution Score and Greenhouse Gas Score (DOE and EPA, 2009). This vehicle is also certified to meet California's tough super-ultra-low-emission vehicle (SULEV) standard. For 2009 and many prior years, the American Council for an Energy Efficient Economy awarded the Civic GX its greenest ranking, beating clean diesel light-duty vehicles and the Toyota Prius (Stern, 2009).

Based on both engine dynamometer and vehicle dynamometer tests, medium- and heavy-duty vehicles running on natural gas typically outperform comparable diesel vehicles in PM, NO_x, NMHC, CO, and evaporative (hydrocarbon) emissions. Table 4 compares emission reductions of NGVs with those of diesel-fueled vehicles). These data are based on a sampling of tests conducted by the National Renewable Energy Laboratory (NREL) and the West Virginia University Heavy-Duty Vehicle Emission Testing Laboratory.

Table 4: Emission Reductions of NGVs and Diesel-Fueled Vehicles

| Emission | Emission Reduction (%) per Vehicle Type and Fleet to Comparable Diesel Vehicle Type | | | | | | |
|-----------------|---|---------------------------------------|------------------------------------|--------------------------------------|---|---|--|
| | CNG Delivery Trucks (United Parcel Service) | LNG Buses (Dallas Area Rapid Transit) | LNG Semi Trucks (Raleys) | LNG Refuse Trucks (Waste Management) | LNG Dual-Fuel Refuse Trucks (LA Bureau of Sanitation) | CNG Buses with MY 01 CWI Engines, Compared to MY 04 DDC WMATA | CNG Buses with MY 04 John Deere Engines, Compared to MY 04 DDC WMATA |
| PM | -95 | NSS ^a | -96 | -86 | NSS | -60 | -84 |
| NO _x | -49 | -17 | -80 | -32 | -23 | +6.1% | -49 |
| NMHC | -4 | -96 | -59 <diesel THC ^b | -64 <diesel THC | NSS | EQN ^c | EQN |
| CO | -75 | -95 | +263 | +80 | NSS | EQN | EQN |

^a NSS = not statistically significant, ^b THC = total hydrocarbons. ^c EQN=Emissions Quantity Negligible.
Sources: Chandler, Eberts, and Melendez, 2006; Zuboy and Melendez, 2008.

Petroleum and Carbon Benefits of Natural Gas Vehicles

Petroleum and carbon benefits of NGVs are estimated using Argonne's Greenhouse gases, Regulated Emissions, and Energy Use in Transportation (GREET) model. The model estimates the full fuel-cycle energy use and emissions for alternative transportation fuels and advanced vehicle systems for LDVs. However, it can approximate larger (i.e., medium- and heavy-duty) vehicles. In addition, it can examine many different natural-gas-based fuels, such as CNG, LNG, methanol, and Fischer-Tropsch diesel (FTD). When natural-gas-based fuels are examined, a key assumption is the origin of the natural gas. GREET assumes as a default that CNG and LNG come from North American conventional sources.

On a miles per gasoline gallon equivalent (mpgge) basis, GREET currently assumes that a dedicated light-duty CNG vehicle has an energy equivalent fuel economy that is 5 percent lower than that of a comparable conventional gasoline ICEV. For heavy-duty vehicles, as noted in table 4, NREL tested two types of Washington Metropolitan Area Transit Authority (WMATA) buses, CNG and low-sulfur diesel, and found that their fuel economy was very similar and in some cases better on a miles per gallon diesel equivalent (mpgde) basis, with the results varying slightly by model year and type of emission control (Chandler, 2006).

In 2010, on the basis of default GREET assumptions, a 23-mpgge light-duty gasoline ICEV's full fuel-cycle fossil-energy use would be 5,928 Btu/mi; its petroleum energy use would be 5,274 Btu/mi; and its greenhouse gas (GHG) emissions would be 478 g/mi. The results for comparable vehicles using CNG and LNG, both from North American natural gas, are shown in table 5. Both natural gas pathways result in significant (about 99 percent) petroleum displacement and modest reductions (about 15 percent) in GHG emissions. While there are currently no light-duty LNG vehicles in the U.S. market, this approach shows the general trends of gasoline versus natural gas fuels. In addition, the table shows that LNG vehicles are slightly more energy and emission intensive than CNG vehicles because of the liquefaction process; this insight applies to heavy-duty vehicles as well.

Table 5: Energy Use and GHG Emissions of Light-Duty Natural Gas and Gasoline Vehicles

| Vehicle | Fossil Energy (Btu/mi) | Petroleum Energy (Btu/mi) | GHG Emissions (g/mi) |
|--------------|------------------------|---------------------------|----------------------|
| Gasoline LDV | 5,928 | 5,274 | 478 |
| CNG LDV | 5,886 | 31 | 405 |
| LNG LDV | 6,137 | 66 | 407 |

Source: GREET, 2009

The results for a 3.1-mpgde CNG transit bus and a 3.0-mpgde transit bus are shown in table 6. For heavy-duty CNG vehicles, the same large reduction in petroleum use and the moderate reduction in GHG emissions, compared to the conventionally fueled diesel vehicle, occurs.

Table 6: Energy Use and Emissions of 2004 Transit Buses

| Vehicle | Fossil Energy (Btu/mi) | Petroleum Energy (Btu/mi) | GHG Emissions (g/mi) |
|---|------------------------|---------------------------|----------------------|
| Diesel transit bus (2004 model year engine) | 51,320 | 46,642 | 4,197 |
| CNG transit bus (NA NG) (2004 model year engine) | 47,834 | 316 | 3,246 |
| CNG transit bus (NNA NG) (2004 model year engine) | 53,036 | 574 | 3,653 |

Source: Chandler, Ebertz, and Melendez, 2006

Argonne is currently finalizing a report on the energy use and emissions of renewable natural gas, and preliminary results show that the fossil energy use, petroleum energy use, and GHG emissions are near zero.

Historical and Current Activities or Strategies Being Implemented

The DOE Office of Energy Efficiency and Renewable Energy (EERE) Vehicle Technologies (VT) Program has supported the market for natural gas vehicles in three ways: (1) research and development (R&D), (2) technology transfer, and (3) deployment through the Clean Cities Program, Advanced Vehicle Testing Program activities, and mandated fleet programs.

Research and Development

Beginning in fiscal year (FY) 1999, DOE launched a range of R&D efforts on NGVs (primarily medium- and heavy-duty), from proof of concept to near-term vehicle and engine development, to commercialization and infrastructure development. In 2002, the Natural Gas Vehicle Technology Forum, a diverse group of industry stakeholders, was created to consolidate DOE's R&D efforts on NGVs and advise DOE on research needs. DOE focused its research — including its work on four types of engine technologies (spark-ignition lean burn, spark-ignition stoichiometric, compression-ignition dual-fuel, and compression-ignition direct injection) — on developing Class 3–6 CNG vehicles and Class 7 and 8 LNG vehicles that would meet 2007 emission standards. Work that began under this program, known as the Natural Gas Engine and Vehicle Research and Development Program, led to development of CWI's spark-ignition stoichiometric ISL G engine (which already meets the 2010 EPA highway heavy-duty emission standards) as well as other technologies used in commercial products.

Research has also been conducted on renewable natural gas, including development of cost-effective methods of methane gas recovery and cleanup from landfills and other biomass sources for conversion to LNG. Before landfill gas can be used for transportation fuel, the contaminants and most of the CO₂ must be removed. With the support of a DOE Small Business Innovation Research grant, Acirion Technologies developed its CO₂ Wash™ landfill gas purification technology and demonstrated the process at a landfill in New Jersey. The goal was to produce 10,000 gallons of LNG from landfill gas for two Waste Management refuse trucks on commercial collection routes totaling 600 hours (EERE, 2005).

Another area of research involves development of small-scale natural gas liquefiers for LNG production. A small-scale system gathers natural gas from a transmission pipeline at a point where the pressure is dropped for commercial distribution. As the gas pressure decreases, the gas expands and cools and is used as a coolant in the liquefaction process. A small-scale plant was built in Sacramento, California, to liquefy 10–20 percent of natural gas entering the plant and produces 10,000 gallons of LNG each day. The plant technology was tested successfully and is now available to be licensed for commercial manufacturing.

DOE has also funded a safety evaluation of FuelMaker Corporation's *Phill* home refueling appliance. Thirty-three residential garages equipped with the *Phill* were evaluated to determine their design, construction, and air infiltration characteristics, and computer modeling was used to calculate garage gas concentrations from potential leaks. Risk scenario probabilities were identified and calculated; it was determined that the annual probability of a deflagration due to misuse failures is 1 in 7 million. In addition, the safety evaluation led the manufacturer to

incorporate suggestions from the study in the final design of the *Phill* (Waterlan, Powars, and Stickles, 2005).

By 2006, budget priorities had changed, and DOE ended its research programs on NGVs and infrastructure. However, the industry forum was maintained by the California Energy Commission (CEC). In 2008, the forum partners met once again to discuss priorities for the NGV industry (AFDC, 2009f). Their recommendations are discussed in the “Barriers in the Marketplace” section of this document. (For a complete account of all NGV and infrastructure R&D, see a draft report, *A Foundation for the Future: Natural Gas Vehicle and Infrastructure Research and Development Sponsored by the U.S. Department of Energy, 1999-2006* [Zuboy and Melendez, 2008].)

Technology Transfer

As noted above, the forum of industry stakeholders complemented the DOE R&D program. Clean Cities funded various stakeholder meetings from 2000 through 2005, drawing 60 to 80 attendees, to help prioritize R&D. In addition to DOE Clean Cities, the organizations attending were OEMs, vehicle and infrastructure packagers, national laboratories, government agencies, industry and trade associations, industry research groups, utilities and fuel distributors, fleets, equipment suppliers, and nonprofit firms. Discussions centered on industry coordination and information dissemination, technology updates, and NGV economics and policies.

In addition to the forum, Clean Cities supports the Natural Gas Transit and School Bus Users Group, managed by the Clean Vehicle Education Foundation. Members share lessons learned and problem-solving techniques via Webcasts. The group provides a forum for maintenance staffs of natural gas bus fleets to learn about the latest codes and standards, safety issues, and technologies. It also serves a valuable role by acting as a liaison between the fleet operators and NGV and equipment manufacturers.

Deployment

Since 1993, DOE has funded a voluntary, grass-roots effort to accelerate markets for alternative transportation fuels, known as the Clean Cities Program. Primary support for NGVs and infrastructure has been provided through Clean Cities’ competitive grant programs. Since 1999, more than \$19 million has been awarded competitively to pay for the incremental cost of light-, medium-, and heavy-duty NGVs, landfill gas projects, infrastructure for fleets capable of being centrally refueled, and training and outreach for natural-gas-related projects. All grants have been heavily leveraged with funds from industrial and other partners. In 2007, 86 of the 87 Clean Cities Program coalitions reported that 41 percent of the total alternative fuel displacement was from NGVs, *primarily medium and heavy-duty trucks and buses* (Johnson and Bergeron, 2008). In 2008, this total replacement figure grew to 53 percent (Johnson and Bergeron, 2009). Technical support through Clean Cities Tiger Teams has been able to solve specific infrastructure or fleet problems. Clean Cities has helped communicate best practices for the natural gas industry. Its efforts have resulted in a CD-ROM titled *Compressed Natural Gas: A*

Suite of Tutorials, an extensive repository of information on NGVs, codes, and standards and infrastructure. Evaluation of CNG fleets has also been funded; an example is a study of the SunLine Transit (Palm Springs, California), an all-CNG bus fleet.

Beginning in the early 1990s, under the DOE Advanced Vehicle Testing effort, a series of LDV chassis dynamometer emission tests was conducted on natural gas and other alternative fuel vehicles (AFVs). Results were compared to those of otherwise identical gasoline vehicles taken from actual service. Over time, the program grew to include the benchmarking and validation of the performance and capabilities of medium- and heavy-duty advanced vehicle technologies and fuels, including the burning of hydrogen-enriched natural gas.

Two other deployment programs, funded by DOE and created by the Energy Policy Act of 1992, are noted here for their role in promoting NGV acquisitions. First, the State and Fuel Provider Fleet Program mandates the acquisition of a percentage of AFVs by certain states and fuel providers. From 1992 to 2006, more than 32,000 NGVs were acquired from a total alternative fuel fleet of 111,320 (AFDC, 2008a). Second, the Federal Fleet Program requires certain federal agencies to acquire a percentage of AFVs each year. In the 2008 reporting period, more than 8,000 vehicles from a federal alternative fuel fleet of 138,000 were natural gas (AFDC, 2009g). Both programs have adopted new provisions since enactment to ensure greater success.

DOE FY 2009 Support for Natural Gas Vehicles

The Clean Cities Program issued a competitive grant program for eligible Clean Cities and its partners in December 2008. A total of \$8.0 million will be available over two fiscal years for vehicles and infrastructure, including natural gas, and for education and outreach workshops. The American Recovery and Reinvestment Act of 2009 has boosted funding for AFVs and infrastructure in 25 Clean Cities areas to historic levels. For natural gas vehicle projects 3,570 CNG and LNG vehicles are estimated for purchase, with the construction of an extensive refueling network of 132 natural gas stations. Project periods will consist of 4 years.

Clean Cities funds the AFDC, through NREL. The Web-based data center includes an extensive natural gas portal, with important topics on NGVs and infrastructure. In FY 2009, NREL will also complete a business case study on natural gas. Clean Cities is also funding an Argonne review of several pilot-, commercial-, and pre-commercial-scale projects that use alternative processes to convert landfill gas into vehicle fuel. In the GREET model, Argonne is characterizing these processes and developing energy and emission inputs to represent landfill gas-to-LNG and -CNG pathways. Landfill gas pathways will be compared with other pathways on a well-to-wheels basis.

Barriers in the Marketplace from Research to Deployment

Product Availability

For the long term but not necessarily delayed in start-up, vehicle integration should be a key focus of research, since this is a major barrier to the deployment of more natural gas trucks and other vehicles. Since 2007 only one OEM has offered a light-duty natural gas product. Small-volume manufacturers, due to the volume of their production, have difficulty with the EPA certification process as it results in additional costs and resources. Small volume manufacturers and fleet users cite the process as complicating product availability in offering products in a timely fashion. In regard to heavy-duty engine manufacturers, two companies offer engines certified to 2010 emission standards.

As previously noted, the Natural Gas Vehicle Technology Forum, a diverse group of industry stakeholders, was created to consolidate the DOE R&D efforts on NGVs and advise DOE on research needs. While Clean Cities is not authorized to fund research and development programs, it may be able to assist to some degree in demonstration and technology transfer efforts. To achieve a robust penetration of NGVS, industry stakeholders at a Forum meeting in November 2008 agreed on the research, demonstration, and deployment needs listed in table 7 (EERE, 2008b).

Emissions Testing Data

In addition to increasing the number of vehicle options, the lack of recent MY testing and evaluation data of on-road natural gas heavy-duty vehicles is problematic. According to Davies, Findsen, and Pedraza (2005), data to properly quantify the benefits of natural gas relative to diesel fuel are not yet available. They do discuss what level of testing will be necessary to provide reliable estimates in the future. For now, their findings are that the relative GHG effects of natural gas versus diesel are close to one another. In the “cleanest” comparison — for the same vehicle type on the same driving cycle with a natural gas and diesel version of the same engine block family from the same manufacturer — natural gas was better than diesel, as is also implied in table 6. However, other data and comparisons did not consistently favor natural gas, and Davies et al. concluded that no statistically reliable conclusion could be reached. In none of the comparisons did there appear to be any evidence of a GHG penalty, so carefully moving forward with NGVs for energy security is not a risky strategy with respect to possible GHG concerns. With careful future testing and quantification and proper incentives and penalties to encourage use in best markets, natural gas can likely be implemented in transportation over the long run, in a manner that both improves energy security and reduces GHG emissions.

Water Issues

Adequate supplies of domestic natural gas appear to have been addressed with recent shale finds; however, some states are interested in limitations on the production of such gas due to possible

Table 7: Research, Development, Demonstration, and Deployment Actions Identified at NGVTF Meeting, November 2008

| Description | Estimated Cost |
|--|----------------------------|
| Engine Development and Vehicle Integration Recommendations | |
| Integrate available natural gas engines into more models and applications by OEMs. | >\$1.0 million |
| Develop a broader range of heavy-duty natural-gas engine sizes and applications and improved efficiencies. | >\$2.0 million |
| Develop NGV versions of off-road applications. | ~\$1.0 million |
| Develop a variety of hybrid natural-gas heavy-duty vehicles. | ~\$1.0 million |
| Develop engine technology optimized for hydrogen/CNG blend (HCNG) fuel. | ~\$1.0 million |
| Develop natural-gas vehicle homogeneous charge compression ignition (HCCI) engine technology. | ~\$1.0 million |
| Fueling Infrastructure and Storage Recommendations | |
| Develop legacy fleet engine controls and or fueling infrastructure upgrades to accommodate fuel variability. | ~\$1.0 million |
| Research an improved composite tank safety device and installation protocol to avoid rupturing the tank in a localized fire. | ≤\$500,000 |
| Develop improved handling, reliability, and durability during LNG dispensing and on-board storage. | ≤\$500,000 |
| Develop on-board, low-cost, lightweight, comfortable, and compact CNG storage at a lower pressure and higher density. | >\$1.0 million |
| Provide global positioning system (GPS) guidance to NGV fueling station locations. | In process by Clean Cities |
| Develop the next generation of home refueling technology | ~\$1.0 million |
| Technical and Strategic Studies Recommendations | |
| Revitalize the Natural Gas Vehicle Technology Forum. | <\$500,000 |
| Update the roadmap through a Roadmap Advisory Council. | <\$500,000 |

contamination of aquifers and the water requirements for fracturing. Water consumption from natural gas recovery varies with geology and the technology used. In the *Shale Gas: Focus on Marcellus Shale* report, a chief oil and gas representative said that horizontal wells, which have been used for shale formations, would require much more water and sand than to produce conventional natural gas; one vertical well in Barnett Shale required 800,000 gallons (Sumi,

2008). In addition, experience with Barnett Shale suggests that horizontal wells can require up to five times the water used by vertical wells (Sumi,2008). Initial drilling requires a large amount of water withdrawal and consumption. Once production begins, the well generates produced water along with the gas/oil mix, which can be re-injected or disposed. Sumi notes that a well drilled in the Marcellus Shale may have to be hydraulically fractured, or “fracked,” several times over the course of its life to keep the gas flowing and that each fracking operation may require more water than the previous one. A majority of the water returns to the surface, and this “flow back,” or wastewater, from these operations needs to be treated or disposed. Historically, because of the cost of treatment of its contamination, the flow back has been put in disposal wells. However, where water resources dwindle, it will be necessary that the water be treated and potentially reused in these operations.

The Ground Water Protection Council (GWPC), an association of state “resource protection professionals, has been characterizing the shale gas resource and its production requirements, including water consumption (Ground Water Protection Council and ALL Consulting, 2009). This study concluded that “water use for shale gas development will range from less than 0.1% to 0.8% of total water use by basin.” (p. ES-4). On behalf of the GWPC, Scott Kell recently testified that “As a result of our regulatory review and analysis, the GWPC concluded that state oil and gas regulations are adequately designed to directly protect water resources through the application of specific programmatic elements such as permitting, well construction, hydraulic fracturing, waste handling and well plugging requirements.” Recommendations for improvements were included in the testimony.

The perspective of Sumi relates to the relative water intensity of shale gas production in comparison to traditional onshore natural gas production. It is important to note, however, that shale natural gas production probably consumes considerably less water per unit of energy delivered than coal production, ethanol production, tar (oil) sands, and oil shale, among others. Though more independent research on the topic is underway, Chesapeake Energy (May, 2009), quoting the GWPC characterization of shale, and DOE characterizations of other fuels, has compiled a fact sheet that implies that once full fuel cycle water use evaluations of various sources of energy have been completed, shale gas will be among the lower users, even if it is more water consumptive than present natural gas production.

Concerns over proper treatment of water may well slow some shale development. The GWPC acknowledges that circumstances vary, and water issues are best addressed according to local conditions.

Disinterest of Utility Partners

Other deployment barriers include utility partners in some areas of the country that no longer find value in marketing NGVs. Once these objections are understood, a strategy to engage key utility partners by high-level officials at DOE could renew interest in greater vehicle deployment.

Lingering Perceptions

Another challenge is that the industry is still fighting perceptions from the past, when less-than-robust natural gas engines were deployed in the early 1990s. Some fleet managers with adverse experiences remain in these positions or have been promoted and given higher decision-making authority, preventing any new introduction of vehicles. Bertram et al (2009) concluded that the reliability of diesel engines in medium duty trucks provided a better explanation for their expanded use than did fuel savings.

High Cost and Lack of Infrastructure

In some cases, especially for large municipal fleets, the high cost of infrastructure is still a barrier, even though incentives are available for tax-exempt fleets that can assist with shortening the payback period. Often these fleets are not even aware of the tax benefits. With less than 1,000 natural gas stations nationwide, fleets that operate on longer routes cannot justify making the switch unless additional public- and private-sector partners come together to build or make available existing stations along key routes.

Opportunities in the Marketplace

Intra-city Trucks, Transit Buses, and Off-Road Vehicles

One optimistic source for future use of natural gas in heavy-duty transport is the California State Alternative Fuels Plan of December 2007. This source estimates a maximum amount of alternative fuels in year 2022 (CEC, 2007, Table 4, p. 41). Of this total, about 17 percent is natural gas. This report sees natural gas as being primarily an intra-city “return to base” heavy-duty fleet vehicle transportation fuel, although the possibility of using CNG in LDVs in small quantities is also considered. The report includes scenarios to 2050, one of which includes a very significant penetration of natural gas (36 percent) in heavy-duty transport.

Applying this 36 percent penetration by 2030 to EIA projections (EIA data projects only to 2030, not 2050) and GREET modeling of U.S. on-road heavy-duty vehicle use (including transit buses), a reduction of approximately 1.2 million barrels of oil per day could be achieved, with a comparable increase in domestic natural gas use. While not the primary focus of Clean Cities, similarly, if 36 percent of the off-road vehicles used in construction and industry were replaced with NGVs, a further reduction of almost 400,000 barrels of oil per day could be achieved. In 2030, both areas — on-road heavy-duty and off-road vehicles — are estimated to use a total of 4.5 million barrels of oil daily.

In terms of natural gas consumption in the transportation sector, the nation would consume 2.5 quads and 0.8 quads of natural gas largely in commercial trucking and in off-road vehicles, respectively. Currently, 8 quads of natural gas is consumed in the residential and commercial sectors. 8.1 quads in the industrial sector, and 6.8 in electric power generation (EIA, Annual Energy Review, 2009 [June]) Furthermore, current petroleum consumption in the transportation sector is 28 quads.

Commercial trucking vehicles are actually quite diverse. Bertram et al. (2008, 2009) recently examined long-term U.S. trends in commercial truck fuel use, studying shifts from gasoline to diesel fuel. They divided commercial trucks into heavy-, medium-, and light-duty trucks, based on a size and configuration accounting format used by the Federal Highway Administration (FHWA), and also divided heavy commercial trucks into combination trucks and single unit trucks. Recent data suggest a possible reversal in the long-term trend toward increased dieselization in single-unit trucks. Since 2007, the gasoline share of commercial single-unit truck sales increased by 20 percent or more, depending on size class (*Light and Medium Truck*, 2008).

Diesel fuel prices *relative to* gasoline prices have recently jumped (Table 2, also EIA, 2009 (Sept.) Petroleum Navigator Website), even after crude oil prices collapsed in late 2008. This increase has occurred as ultra-low-sulfur diesel fuel has been introduced, and U.S. and world demand for gasoline has dropped. Whether the new increment in diesel cost relative to gasoline cost is permanent remains to be seen. However, in the future, natural-gas-fueled medium and light duty trucks probably should be compared not only to diesel-fueled heavy-duty vehicles but also to gasoline-fueled trucks, particularly single-unit trucks used for urban delivery. Further, those who are considering GHGs are increasingly thinking long term, so the evaluation should cover possible events over several decades. Further, as the TIAx study (2005) found, efforts to make the diesel engine as clean as the gasoline engine appear to be significantly changing the relative economic merits of diesel (the new “clean” diesel) versus other fuels. The capability of U.S. commercial truck natural gas engines has been developed over two decades. The kinks are largely out of them, and, as observed earlier, some of the engines already meet the 2010 tailpipe emission standards that many diesel engine manufacturers have struggled with.

Combination trucks (FHWA heavy) dominate inter-city transport and have relied on diesel fuel for many decades. FHWA medium trucks predominantly serve intra-city transport and have come to rely almost exclusively on diesel fuel only in the last 30 years. FHWA light commercial trucks have increasingly adopted diesel fuel over the last 20 years. Among the three categories, Bertram et al. (2008) estimated that in 2002, FHWA heavy (combination trucks) used 15.4 billion gallons of fuel a year; FHWA medium (6 tire or more straight trucks) used 6.8 billion; and FHWA light trucks (commercial 4-wheel, 2-axle trucks) used 13.8 billion, for a total of 36.1 billion gallons per year. EIA estimated the total on-highway distillate fuel consumption for 2002 to be 34.3 billion gallons (EIA, Dec. 2008, Petroleum Navigator website). The estimates of Bertram et al. included gasoline-fueled commercial trucks, thus their number is higher. According to their estimates, gasoline use was dominant in the FHWA light truck category (less than 10,000 lb. GVW). For light, medium and heavy commercial trucks approximately 57 percent of their 2002 fuel use was estimated to be by single unit (urban delivery) trucks. About two thirds of that is 4-tire, 2-axle trucks.

The latter class of truck is at the heavy end of gasoline fueled vehicles long manufactured by Ford, GM, and Chrysler and more recently by Asian manufacturers, with Toyota being relatively successful. Although the only light-duty CNG vehicle now available is a passenger car — the Honda Civic GX — as recently as 2004 CNG models were available from Ford and GM in both pickup trucks and standard sized vans. Based on the availability of the CWI and Emission Solutions natural gas engines for medium-duty truck applications, the estimates above suggest

that 36 percent of “EPA-heavy” duty (8500 lb. GVW and up) on-highway fuel use replacement by CNG in urban areas is technologically feasible, though considerable engine technology (re)development and refinement across a wider range of truck offerings would be necessary, consistent with R&D needs noted in Table 7.

In some respects, this medium-light commercial truck market penetration scenario seems aggressive, considering historical achievements for CNG use in U.S. transportation. Nevertheless, we noted earlier that CNG use worldwide has been expanding dramatically, generally in nations with considerable domestic natural gas supplies and little domestic oil. Egypt and Argentina are two nations that have been oil short and gas rich for decades. This has not been the U.S. circumstance in the past. However, recent trends in the ratio of domestic U.S. gas and oil reserves will make the U.S. much more like Egypt and Argentina in the future. Egypt and Argentina use natural gas not only in commercial vehicles but also in some personal LDVs. Argentina is probably the nation with greatest market penetration of natural gas, having started in 1980. Gas prices were held low as a matter of public policy (recently 70 percent cheaper than gasoline). Taxi fleets were converted first, and personal-use vehicles followed. Today, nearly 30 years later, about 15 percent of Argentine vehicles are fueled with natural gas and natural gas refueling stations are common (Bridges, 2008). Such price controls would obviously not be possible in the United States, but in terms of numbers of vehicles, the U.S. commercial vehicle scenario referred to above — though admittedly aggressive — would be well below 15 percent of vehicles nationwide.

CNG is not the only way to use natural gas to provide transportation services. LNG can be used where range is important. Fischer-Tropsch diesel (gas-to-liquid, or GTL) could also be used, but is not desirable from a GHG perspective. Natural gas is an excellent fuel for power generation, which in turn can provide miles of service via electric drive for passenger cars and small SUVs, with even lower GHGs per mile than CNG (Gaines et al., 2009). Medium-light commercial truck use of CNG sits in a potential “sweet spot” where more range is needed per day than can be provided economically by batteries in electric vehicles and plug-in hybrids. However, less range is necessary than with large inter-city combination trucks, where LNG (requiring new infrastructure) or GTL (emitting more GHGs) would be necessary to provide the needed range via natural gas feedstocks.

Supply of Natural Gas

Given the last decade’s expansion of domestic natural gas reserves, the supply of natural gas does not appear to be a barrier to significant growth in the NGV market. Moreover, renewable natural gas could provide an additional future supply. Thus, a reasonable transition strategy might be to concentrate on larger fleets in the medium and light commercial truck market (primarily intra-city trucks or single-unit CNG vehicles), where central refueling offers convenience and lower infrastructure cost to the end user, as well as the possibility of securing lower cost supplies under long-term contracts. In addition, the off-road market would complement on road use and supplement petroleum reduction, with additional environmental benefits. Very promising CNG technology is already available for many of these fleet customers, already meeting 2010 emission standards. In the very near term incentives are available to help offset increased up-front capital costs attributed to the vehicle or fuel station, but these do not

last nearly as long under current legislation as incentives for plug-in hybrids, which last until 2014 (AFDC, 2009g).

Even with the expansion of domestic natural gas reserves, which the CEC study projects, it is unlikely that natural-gas-fueled vehicles could replace a large portion of light-duty gasoline-fueled vehicles. However, it is possible that natural gas might forestall a revival of gasoline use in medium-duty trucks. Natural gas could be a big niche fuel with market shares in the tens of percentage points, as projected in the CEC report. Such share totals are quite conceivable (in the absence of a prompt reversal in the trend of growth of natural gas reserves). The most cost-effective approach would likely involve a regional focus on natural gas, where the market is near the resource base.

Since there is long-term potential, short-term policies may be justified. In addition, there is now a large funding source as a result of the American Recovery and Reinvestment Act of 2009. Funds are available through 2010 (Table 3) to reduce buyer's incremental costs for natural gas vehicles and infrastructure. Actions should begin now to ensure the future success of the market. Two short-term strategies are suggested to be desirable to enhance the probability of long duration success of natural gas commercial vehicles: (1) "quality assurance" via on-road demonstration to determine durability, with some tracking of emissions rate reliability (deterioration) of the CNG trucks and particularly their clean diesel competition, supported by (2) extension of some incentives beyond 2010. Furthermore, a renewed emphasis by Clean Cities and key stakeholders must also occur to help place available natural gas trucks in the best segments of the market niche we have designated.

Emissions and Durability Testing

Although deployment is the primary responsibility of Clean Cities, not vehicle testing, early, well-organized field testing of logically competing MY 2010 CNG, clean diesel, diesel hybrid, and gasoline powertrain sets should be encouraged by Clean Cities. Deployment efforts are inevitably related to the information available on emissions and fuel consumption attributes of vehicles being selected for emphasis. Given the major turnover of engine and emissions control systems in 2010, it is desirable that quality data be promptly available demonstrating when criteria pollutant and GHG neutrality or improvement via use of natural gas is assured (in comparison to gasoline, diesel or, particularly, diesel hybrids). It is very unlikely that a new round of emissions standards will be passed in the next decade. Accordingly, there is likely significant benefit of early tracking of the new emissions control technologies being used to meet 2010 standards, since the best of them will likely be in use for a decade or more. Avoidance of surprises is particularly desirable in light of possible competition between natural gas and diesel hybrid trucks. Existing engine dynamometer certification test procedures for commercial trucks cannot properly evaluate hybrids. There has already been a revision to testing for customer information in light duty vehicles, partly in response to debates about the true fuel economy of light duty hybrids and, to a lesser extent, diesels (Environmental Protection Agency, 2006, and fueleconomy.gov). Testing on vehicle dynamometers (such as the DOE WVU test dyno) and possibly in-use emissions measurement for light and medium commercial trucks is possible and desirable for the target market suggested here (Davies et al., 2005). This is particularly true if

and when (probably later than 2010) hybridization of natural gas trucks is to be implemented, according to one of the stakeholder and CEC study research suggestions. Davies et al. do not even suggest use of engine dynamometer tests for accurate determination of in-use GHG and fuel use rates. Early evaluations of 2010 compliant CNG engine durability versus the new clean diesel systems in selected fleets should be considered. In contrast to emissions testing — which is not Clean Cities' responsibility — this is probably a suitable use of deployment funds. Solicitation of funding of periodic emissions tests from other DOE offices or federal agencies or local jurisdictional districts (i.e. large metro area air quality control regulatory bodies) in conjunction with such fleet field evaluations, could be considered.

Good test data on emissions, durability, maintenance costs, etc., in a variety of applications would clearly assist Clean Cities coordinators and fleet managers understand the benefits of natural gas vehicles and could help them support wise purchase decisions by transit, private and municipal fleets.

Extension of Tax Credits and Fuel Excise Tax and Other Incentives Evaluated

Short-term incentives that should be considered include extending the vehicle and infrastructure tax credit and fuel excise tax credit beyond their current expiration dates to 2011 or beyond to help engine manufacturers continue to sell natural gas engines and provide additional cost savings and greater convenience to fleets with additional fueling stations. There does appear to be a potential problem with the scheduled end of current incentives in December 2009 and 2010. It is unlikely that sound evaluation of MY 2010 trucks can be completed in time for Congress to develop appropriate new incentives for the following decade without a gap in incentives in 2011. Such a gap could create significant problems for engine and truck manufacturers if customers wait for new policy measures to be implemented.

Other policies should be analyzed further, including developing an incentive for fleets to trade in old high-emitting diesel vehicles and replace them with NGVs. This could be similar to the current Cash for Clunkers program, which has allowed consumers to upgrade their old vehicles to more fuel-efficient models. Promoting the replacement of older single-unit diesel trucks with new CNG vehicles could provide rapid reductions in criteria pollutant emissions, which would improve local air quality and accelerate market penetration. Without such incentives, a slump in clean new commercial truck sales could continue well into 2010 and beyond as owners hold on to older, much "dirtier" diesels for an extended period.

The importation of U.S. automakers' larger light-duty NGVs, manufactured abroad but still meeting U.S. emission and safety standards, would help stimulate the intended niche market. While in the short term the vehicle-manufacturing jobs would be overseas, the expansion of natural gas output would be domestic, dealers would have product to sell, and the stage would be set for domestic LDV manufacturers to begin producing NGVs once again.

Clean Cities

The Clean Cities network of nearly 90 cities, covering 73 percent of the population, is poised to help DOE implement a major deployment effort in intra-city trucks and off-road vehicles and renewed emphasis on transit. While the Clean Cities Program has focused on these niche markets in years past (with the exception of off-road), the program could develop new tools including materials that address the following:

- supply of natural gas;
- results from new testing of emissions and durability;
- product offerings meeting 2010 emission standards;
- fuel economy and performance;
- safety concerns for fleets (and for small businesses and consumers, should single vehicle overnight refueling equipment like the *Phill* be marketed once again); and
- payback period for the total investment by a fleet, including the initial vehicle cost, operating cost (fuel, maintenance, product longevity, insurance rates, and resale value).

While Clean Cities is more focused on on-road vehicles, off-road vehicles can potentially help build throughput to assist in making infrastructure economical. Evaluating the costs and benefits of off-road alternative fuel options should be a priority. In addition, technician training seems to be lacking in some areas of the country; therefore, an analysis could show where best to provide training and recommend ways to spur involvement of current training centers. Also, Clean Cities could benefit from understanding the work force potential of a strong NGV industry. This would provide an additional impetus for state and local policy makers, for instance.

Utilities that were once engaged in promoting NGVs must revitalize their efforts to deploy NGVs in their own fleets and promote these vehicles to fleets and other consumers in their communities. Again, with federal leadership and support, including Clean Cities, could play a key role.

In addition to utilities, Clean Cities should work with key national fleets, a list that has already been developed. While not every organization will select natural gas as the fuel of choice, it is a good opportunity to present options and assist targeted fleets with significant intra-city vehicle operations, to large warehouses using off-road equipment, and possibly off-road equipment moving cargo containers within ports. In tandem with that approach, Clean Cities could develop a Corporate Imaging Program, including awards to fleets making significant purchases that could be promoted to national media outlets.

Ultimately, if the challenges and opportunities cited above are addressed, a significant long-term attainable penetration of 36 percent in natural gas in commercial truck transport and off-road vehicles could result in petroleum reduction for the entire nation of 1.6 million barrels of oil per day, from a total of 4.5 million barrels per day of oil used in the two sectors.

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